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REMOTELY OPERATED HYDREMA FLAIL SYSTEM MILITARY UTILITY ASSESSMENT FINAL TEST REPORT

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14. ABSTRACT
The Hydrema 910 MCV-2 Flail System is a commercially available mine clearing system designed by the Swedish government to be manually operated. The HQ Air Combat Command Civil Engineer (HQ ACC/CE) has expressed strong interest in being able to remotely employ the vehicle system thereby removing the man-in-the-seat during mass area clearance operations in an effort to improve personnel safety. The effort to integrate a remote control system is currently funded through HQ ACC/CE. The Hydrema military utility assessment supports the continuing developmental testing effort to establish the effectiveness (high degree of driving accuracy and positioning) of teleremote operations as a means of employing the mine clearing system.

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REMOTELY OPERATED HYDREMA FLAIL SYSTEM

DEVELOPMENTAL TEST AND EVALUATION (DT&E) TEST REPORT

13 JULY 2005

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Hydrema Developmental Test & Evaluation (DT&E)
Test Report

1.0 Background

The Hydrema 910 MCV-2 Flail System is a commercially available mine clearing system designed by the Swedish government to be manually operated. The HQ Air Combat Command Civil Engineer (HQ ACC/CE) has expressed strong interest in being able to remotely employ the vehicle system thereby removing the man-in-the-seat during mass area clearance operations in an effort to improve personnel safety. The effort to integrate a remote control system is currently funded through HQ ACC/CE. The Hydrema Developmental Test & Evaluation (DT&E) supports the continuing developmental testing effort to establish the effectiveness (high degree of driving accuracy and positioning) of teleremote operations as a means of employing the mine clearing system.

2.0 Test Objective. The main objective of this DT&E is to provide initial engineering development data and to provide controlled experimentation on the user's effectiveness in the teleremote employment of the Hydrema Flail System.

3.0 System Description. The remotely operated Hydrema Flail System is composed of two major subsystems: 1) the Hydrema 910 Mine Clearing Vehicle (MCV) and 2) the integrated Remote Control System.

3.1 Hydrema 910 MCV. The Hydrema 910 Mine Clearing Vehicle is integrated onto an articulated chassis so that all four wheels are in contact with the ground at all times. When being driven on roads the cab is to the front, during mine clearing operations, the vehicle is driven in reverse with the cab to the rear. The fully enclosed, all-welded steel armor cab protects the occupants from small arms fire up to 7.62 mm armor piercing rounds and the bullet-proof windows provide all around visibility. For increased crew comfort during travel and mine clearing operations, the cab is suspended in rubber elements to dampen vibration. The cab seats three people although the vehicle can be operated by a single operator.

The vehicle is powered by two Perkins 1006-6TW 6-cylinder turbocharged diesel engines. One is used for driving the vehicle and is coupled to a six-speed semi-automatic transmission. The second diesel engine powers the mine clearing flails. Each engine has its own cooling, air filter, exhaust and hydraulic system. During mine clearing operations, a separate hydrostatic transmission is used which gives a continuously variable speed and considerable tractive force. The hydrostatic driving unit can be supplied from the hydraulic system of the powerpack and can be used in an emergency should the main engine stop, enabling the Hydrema 910 to move out of immediate danger under its own power.

The MCV can be manually driven on roads up to a maximum speed of 35km/h. The vehicle is steered through a hydrostatic pivot steering system on all four wheels with an emergency backup in case of engine failure. The fuel tanks hold 300 liters and are integrated onto the chassis for

maximum protection. When in the travel mode, the complete flail system and deflector, which is suspended on hydraulic systems, is raised clear of the ground and traversed through 90° using a hydraulically operated tilting/turning system so that it is in line with the chassis. In this configuration, it can be driven on public roads.

For mine clearing operations, the complete flail system is rapidly lowered into position at the rear of the vehicle. The system can clear a mine path 3.5m wide. During mine clearing, the vehicle can be manually operated from the cab using a joystick or through the use of a computerized fully automatic pilot steering system . When being used in the latter configuration, the operator needs only to select a number of key parameters, for example depth, on the monitor. The depth control of the flail and the armored deflector plate, which is positioned to the immediate rear of the rotating flail, is then fully automatic using sensors. The chains rotate clockwise if mines are buried and anti clockwise if they are on the surface. The flail assembly consists of a rotating axle to which are attached 72 chains; the end of each of these is fitted with a hammer type head which weighs 0.9kg. When these chains or heads are damaged, they can be easily and quickly replaced. The axle rotates at up to 400rpm, with the speed depending on varying types of terrain. On cross-country terrain, for example, it is about 1.4 km/h while on a firm hard surface it could travel up to 12km/h.

As the system may be required for operations in any part of the world, it is fully air transportable in a Lockheed Martin C-130 Hercules transport aircraft without further preparation, and can be ready to use, once offloaded, within 2 minutes. Figure 1 shows the Hydrema 910 MCV positioned on the test site.

Figure 1. Hydrema 910 Mine Clearing Vehicle

3.2 Hydema Remote Control System. The Remote Control System consists of the following Operator Control Station (OCS) components:

- Laptop Computer with power cord for 110V operations
- Joystick Box (JB) with USB cable
- JB AC Power Adapter
- COM/GPS Case
    - Ethernet Radio
    - GPS Base Station Receiver
    - Single Board Computer
    - Ethernet cable
- 1 Tripod for GPS antenna plus cable
- 1 Tripod for Ethernet radio, antenna, plus cable

The Operator Control Unit (OCU) computer is a standard personal computer with sufficient processing power, memory, and features to perform the OCU functions. The computer uses a Windows operating system loaded with the Joint Architecture for Unmanned Systems (JAUS) control software. The operator's primary display will be from 8 camera views mounted on the vehicle that are displayed through the laptop monitor. The vehicle travel and flail functions are controlled by the operator through the Joystick Box. The network communication uses an 802.11b wireless Ethernet network. The vehicle has a radio unit for RF communications. An RF antenna and a GPS antenna will be used to provide continuous coverage. Figure 2 depicts the OCU laptop and joystick box components of the Operator Control Station. Figure 3 depicts the COM/GPS case and Figure 4 depicts the GPS and RF antennas

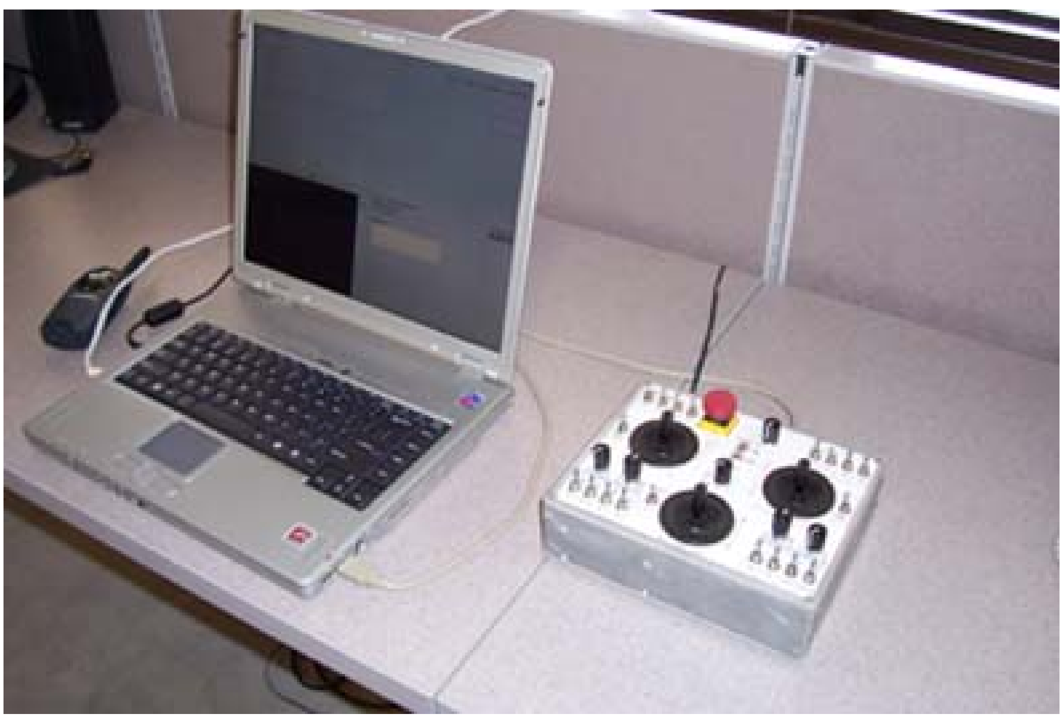

Figure 2. Hydrema Joystick Box and Laptop Computer

Figure 3. COM/GPS Case

Figure 4. GPS and RF Antennas

4.0 Test Design. The test was designed to provide initial engineering development data and to provide controlled experimentation on the user's effectiveness in the teleremote employment of the Hydrema Flail System. Since this was the first time that active duty personnel from Air Force Combat Engineers (10 personnel) and the EOD (2 personnel) community were introduced to this vehicle and its remote control capability, the four day test period was divided into the following five phases:

Phase I	Day 1	Hydrema vehicle orientation and description (classroom) Hands-on vehicle checkout and maintenance orientation (static vehicle)
Phase II	Day 2	Hydrema vehicle manual operations (practice driving and flailing ops)
Phase III	Day 3	Hydrema vehicle remote control operations (practice driving and flailing)
Phase IV	Day 4	Hydrema Remote Control DT&E Test over designated area
Phase V	Day 5	Hydrema Remote Control distance test

5.0 Test Results. Test results were recorded as a measure of the operator's ability to achieve performance goals established for the remotely configured Hydrema System. The following test results were observed during the first three Phases. See Table 1.

Table 1. Hydrema Performance Parameters and Test Results

HYDREMA System Parameter	**Performance Goal**
Vehicle System-Man. Ops • Start engine/s • Drive Fwd/Rev • Deploy Flail • Flail Fwd • Steer Right/Left • Stow Flail • Cleaning/Maintenance	Operator capable of manually performing all subtasks <u>Results</u>: All 12 operators successfully operated the Hydrema vehicle through the vehicles travel and flailing functions with an instructor in the cab. Each operator received approx. 15-20 min. of manual operations time. <u>Operator comments</u>: Not difficult to learn. No problems encountered.
OCS Setup • Laptop computer • Joystick Box • COM/GPS • Tripods/Antennas • GPS/mapping setup • Vehicle cab prep	Operator capable of setting up Operator Control System (OCS) using Op Guide instructions and instructor supervision <u>Results</u>: All operators were instructed in and participated in OCS setup procedures using an Operators Guide and an instructor. Operators quickly learned cable hookup and bootup procedures. GPS/mapping setup procedures took additional practice time. Vehicle cab reconfiguration for remote ops was quickly learned.

Teleremote Operations • Start/Travel Ops • Conduct Flail Ops • Video View Select • Monitor Select • Shutdown procedures	Operator capable of performing teleremote ops using Joystick Box as controller and video display on laptop Results: Operators stated that remote operations were more difficult than manual ops. All operators stated that with more practice they would be able to master teleremote techniques. Each operator experienced difficulties at first but improved as they obtained more "stick time". Steering a straight line was the most difficult for all.
Return to manual ops • Shutdown OCS • Reconfigure veh. cab	Operator capable of reconfiguring vehicle cab for manual ops Results: This task was quickly learned by all operators.
• Remote Control Radio Distance Test	Operator capable of operating the vehicle at the greatest extent of the system possible Results: Vehicle radios reached a best distance of .65 miles in the remote configured operation (Vehicle cab toward OCU.)

6.0 DT&E Test Results. Phase IV consisted of the actual DT&E test on Day 4.

6.1 Test Layout. The test area was 300 feet long and 80 feet wide oriented in an East/West direction. Within that rectangular area, 10 inert ordnance items were placed on the surface or buried up to 4 inches in the sand. Each item was marked with a surveyor stake to provide a visual marker as to its location. The exact location of each device was recorded in latitude and longitude. In addition to the inert ordnance items, 15 items of wood material (scrap lumber) approximately 1-2 feet in length were placed in the test area to act as visual targets to be encountered.

6.2 Test Procedures. The vehicle was manually driven to the test site by one of the Combat Engineers and parked. Before exiting the cab of the vehicle, the driver configured the cab for remote operations in compliance with established procedures. The driver was assisted by one additional Combat Engineer. Once the vehicle was configured for remote operations, the driver and his assistant reported to the Operator Control Station located inside the test support building adjacent to the test site. During this time frame, the remainder of the operators reported to the test site and began setting up the Operator Control Station (OCS) in compliance with set up procedures outlined in the Operators Guide for the Remotely Operated Hydrema Flail System. The GPS and Ethernet antennas were set up, all cables were hooked up between the laptop, the joystick box, the COM/GPS case, and the antennas. Power was applied and the laptop was booted up.

The area to be cleared was mapped on the laptop monitor by two of the operators. The mapping process displays the dimensions and orientation of the area to be cleared and the desired width of

each cleared lane. Once the mapping entries were made, the operators were ready to commence clearing operations. Each of the 12 operators was tasked with clearing one lane 300 feet long. To accomplish this, each operator was required to performed the following remote controlled tasks:

- Maneuvered vehicle to lane entrance – remotely drove vehicle forward and reverse
- At entrance point – stopped vehicle – lowered flail head – lowered blast shield
- Set engine and powerpack engine speeds to operational settings – 2200 rpm
- Initiated rotation of flail
- Commenced forward movement while flailing
- Maintained directional control of vehicle through joystick controller as it traversed 300 foot lane by watching centerline steering indicator on laptop monitor
- At lane end, stopped vehicle – stopped flail rotation – raised shield
- Reversed travel of cleared lane (followed tire tracks) to starting point
- Stopped vehicle and set parking brake. Changed operators.

6.3 Test Results. During the morning test period, 7 lanes were successfully cleared (See Figure 5) by test participants controlling the Hydrema Flail System through the OCU located inside the test building (See Figure 6). During the lunch break, a HUMVEE vehicle (See Figure 7) was positioned adjacent to the test site and the OCS was set up in the backseat of the vehicle (See Figure 8). The next four operators successfully performed their remote lane clearing operations while operating the OCS from inside the vehicle. Unfortunately, test time ran out and the 12th operator did not get a chance to operate the remotely controlled vehicle.

Figure 5. DT&E Hydrema Remote Controlled Clearing Operations

Figure 6. Hydrema Teleremote Control Station inside test building

Figure 7. HUMVEE Vehicle set up adjacent to test building

Figure 8. Hydrema Operator Control Station set up in backseat of HUMVEE

A summary of DT&E test results follow:

- 11 out of 12 operators participated in DT&E remote clearing operations on Day 4
- 10 of 10 inert ordnance items were observed to be in a cleared path
- 15 of 15 scrap lumber items were observed struck by the flail system
- 11 out of 12 operators successfully employed a remotely controlled mine clearing vehicle
- On pass #8, the MACV was moved back into the area that had been previously cleared. During this pass the MACV was observed to bog down and the wheels slipped in the loose fine sand. The operator was able to shift to a lower gear and drove the vehicle out of the area with no further difficulties. See Table 2 for detailed DT&E Test Summary.

Table 2. DT&E Test Summary

Operator/Lane	Distance	Ord Item	Wood Block	DT&E Complete
1	200 ft	None	No	Yes
2	220 ft	#3, #9	No	Yes
3	220 ft	#1, #7	No	Yes
4	300 ft	#5	No	Yes
5	300 t	None	2 Blocks	Yes
6	300 ft	#2	2 Blocks	Yes
7	300 ft	#4, #6	4 Blocks	Yes
HUMV-8	150 ft	#10	2 Blocks	Yes
HUMV-9	300 ft	None	4 Blocks	Yes
HUMV-10	150 ft	#8	1 Block	Yes
HUMV-11	150 ft	None	No	Yes
12	--	--	--	--

7.0 Teleremote Distance Test. This was the final Hydrema test conducted on Day 5.

7.1 Teleremote Distance Test Layout. The test area, the Large Scale Drone Airfield at Tyndall AFB was used for this test. The airfield is 1.7 miles in length including the aircraft over-runs on both ends of the runway. The area is cleared of all brush and trees to a distance of at least ½ mile to either side of the runway. The runway was measured at every 1/10th of a mile and the OCU base station was positioned at the south end of the runway.

7.2 Teleremote Distance Test Procedures. The OCU and MACV were driven to the south end of the Large Scale Drone runway and positioned as it would for clearance operations with the vehicle cab pointed toward the OCU and the flail and shield pointed away from the OCU (north). The flail remained in the stowed position. The MACV was manually driven away from the OCU until there was no longer a video signal. Normally, the video signal will be lost before the data signal. The loss of the video signal was used as the indication for loss of teleremote control of the vehicle. The operator in the cab recorded the distance traveled at the time the video signal was lost for each run.

7.3 Teleremote Distance Test Results. The MACV was driven four times at various positions on the runway with the following results:

Run #1 – Center of runway – Distance driven before video signal loss: .5 mile
Run #2 – Left side of runway – Distance driven before video signal loss: .5 mile
Run #3 – Center of runway, antennas repositioned to the far right hand side of the Robotic Command Post to eliminate any interference – Distance driven before video signal loss: .65 mile
Run #4 – Center of runway, antennas repositioned to the left side and in front of the Robotic Command Post to eliminate any interference – Distance driven before video signal loss: .65 mile
Run #5 – Same as Run #4, but vehicle was driven with the cab forward as in the transport position – Distance driven before video signal loss: .7 mile

NOTE: Teleremote Distance Test will be repeated the week of 9 May 05 to confirm distance data recorded during the first distance trial series and to test a spare set of radios to see if there is any difference.

8.0 Observations/Recommendations

Manual Operations Observations/Operator Statements

- All operators stated vehicle was "easy to learn" to operate
- Drove as easy as a forklift
- Operators were eager to learn and quick studies on manual operations
- No problems encountered

Teleremote Training Operations

- Much more difficult than manual operations
- Driving in reverse is confusing

- Steering a straight line using the steering indicator is difficult
- More “stick time” training is required

DT&E Clearing Operations

> **Note: At this point, each operator had approximately 45 minutes of actual remote control time of the Hydrema Flail System prior to the commencement of DT&E.**

The Data Collector for this test series was in a position to observe each operator as he “took his turn” at the Hydrema Operator Control Unit and laptop monitor. Each operator was able to successfully accomplish the following tasks:

- Maneuvered vehicle to lane entrance – remotely drove vehicle forward and reverse
- At entrance point – stopped vehicle – lowered flail head – lowered blast shield
- Set engine and powerpack engine speeds to operational settings – 2200 rpm
- Initiated rotation of flail
- Commenced forward movement while flailing
- Maintained directional control of vehicle through joystick controller as it traversed 300 foot lane by watching centerline steering indicator on laptop monitor
- At lane end, stopped vehicle – stopped flail rotation – raised shield
- Reversed travel of cleared lane (followed tire tracks) to starting point
- Stopped vehicle and set parking brake. Changed operators.

Considering the minimal amount of training time each operator had received prior to the commencement of this test, the ability of each operator to successfully employ the remotely controlled Hydrema Flail System over a 300 foot lane is a remarkable accomplishment. The operators were enthusiastic, eager to learn, and eager to get more “stick time” so they could improve their performance.

It was also noted that the Hydrema Flail System had no mechanical problems during the test week. In addition, no software or teleremote problems surfaced during the test.

Recommendations

- All operators recommended the next vehicle be equipped with more autonomy to aid in the set up and more autonomy in ordnance clearance operations. Some of the desired autonomy includes:
  - Trouble Shooting Guide for components AFRL/RXQF installed for the remote systems
  - Low Level – Clean up the wiring harness, perhaps work with Hydrema to incorporate the wiring into the vehicle’s wiring system; Change out the video multiplexer for one that provides more versatility like picture in a picture and side by side pictures; Upgraded Pan & Tilt
  - High Level – Automating more of the driving to include return to start of pass in reverse; converting GPS data to make it more visible/tangible to the

operator by providing on screen data, this includes having visualization on the OCU of areas that have actually been flailed.